TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 147.

SPEED MEASUREMENTS MADE BY DIVISION "A" OF THE

AIRPLANE DIRECTORATE (FLUGZEUGMEISTEREI), SUBDIVISION

FOR FLIGHT EXPERIMENTS.

By V. Heidelberg and A. Hölzel.

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Summary.

1. The various speeds of an airplane can only be measured in
    horizontal flight, since there are no means for measuring
    the angle of ascent or descent.

2. The measurements must be corrected for the density of the air.
    This is obtained by simultaneous pressure and temperature
    measurements during flight.

3. Calculation from the mean yearly values in accordance with
    Everling's suggestion (Technische Berichte, Vol. I, No.2)
    can only be considered an approximation, since the distribu-
    tion of pressure and temperature in the individual strata at
    different attitudes undergoes such large variations that the
    yearly mean gives inaccurate values.

4. Thermographs of the present form are useless for temperature
    measurements on an airplane.

5. In altitude data, the following are to be distinguished: the
    height above the earth, the barometric altitude and the alti-
    tude corresponding to the yearly mean air density.

ɔ.   Variometers are not suited for the mechanical control of high
      altitude flight.

Arrangement and Procedure followed in the Experiments.

      Speed measurements were made on seven different airplanes at
altitudes of 2500 to 4000 meters (8200 to 13100 feet), using
Jacoby's method (Technische Berichte, Volume II, No.1, p.99). with
theodolites from two fixed points. The base was 1.4 kilometers
(.87 mile) long. The effect of the wind was eliminated by a trian-
gular flight, each side of the triangle requiring about two minutes
flying time. The readings were taken about every 30 seconds or six
times on each leg. The airplanes carried the required useful load
for the flight.

      The airplane speeds obtained were corrected for the density of
the air. For the sake of clearness, the altitude figures corre-
sponding to the yearly mean on the assumption of normal distribu-
tion of pressure and temperature, are given in the tables and dia-
grams. The air densities were determined in each flight from bar-
ograph curves regarded as pure pressure curves and from temperature
readings on alcohol thermometers. The readings of three thermome-
ters agreed closely.

      In the calculation of these air densities, it is apparent that
computation from the yearly mean, according to Everling's method,
is not reliable and can only be employed as an approximation, since
the distribution of pressure and temperature in the individual
strata is subject to considerable variations. This result was ex-

pected when Everling's method was adopted.

In temperature measurements it was found that alcohol thermometers lagged so much that readings during ordinary gliding flight were inaccurate, although, on the other hand, they registered quickly enough during climbing flight. In order to avoid errors due to lag of the thermometer, readings were not taken until after the triangular flight. Comparison of the readings of thermometers and thermographs showed great inaccuracy in the latter, due to the great difficulty in preventing the oscillation and vibration of the airplane from being transmitted to the thermographs, the recorded curves being so thick that the mean value could not be obtained with certainty.

The measurements are recorded in Table I, three values being given for the altitudes:

1. The actual height above the ground as measured by the theodolites, i.e., the vertical projection.

2. The barometric altitude indicated by the barographs, which corresponds to a calculated air pressure for the yearly mean at all altitudes. A ground temperature of $10^{\circ}C$ is assumed and a temperature decrease of $0.5^{\circ}C$ per 100 meters. The barograph curves were compared with their calibration curves which were obtained by regularly changing the air pressure in a vacuum chamber.

3. From the curve of air density ρ calculated from the temperature and pressure observations, an altitude curve is finally

obtained, which took into consideration the fall in pressure and temperature. In Figs. 1, 2 and 3, the barograph curve, the ordinates of which are originally arcs of circles, is shown by a dotted line. Beside these dotted curves, the mean yearly altitudes, corresponding to the air densities are given.

In Figs. 4 to 8, the temperatures observed in the test flights are plotted against the observed air pressures. The course of the temperature curve for Pfalz D III a and Junkers C I airplanes, is noteworthy. Although both flights lie within the same pressure range, their difference is shown up to 8°C. With Halb CL IV, the temperature falls from +1 to -4°C between 2.5 and 3 kilometers (8200 and 9800 feet) altitude. These examples show that all calculations which depend on the assumption of a temperature fall of 1°C per 200 meters (656 feet) can claim only approximate accuracy in any particular case.

Since the flight characteristics depend only on the air density, all comparative values are to be corrected accordingly. It follows that, in speed flights, neither the actual nor the barometric altitudes are alone involved and we must consequently employ for velocity measurements an air density indicator, which is used in speed flights in place of a barograph and renders superfluous all approximate calculations, of the inaccuracy of which, we have been convinced for some time.

In Figs. 9 to 11, the climbing speed for the standard air density is given, the curve being obtained by differentiating the baro-

graph curves. From these curves it is apparent as to how efficiently an airplane is flown.

In Fig. 12, the horizontal speeds are shown for the standard air density. An example of the calculation of the mean of the three observed speeds of the triangular flight, diagrams of three flights made with Fokker D VII and Junkers C I airplanes are given in Figs. 13 to 18. For airplanes without strut wires and with thick wing sections, the speeds are greater. Moreover, the curves slope rather rapidly downward and within the given range, the speed decreases only slightly with the altitude. On the other hand, the curves for the airplanes with smaller horizontal speeds are flat, i.e., the speeds decrease rapidly with increasing altitude.

Experiments, carried out with variometers during the speed measurements, show that they are useless in practical work. Sensitive variometers clearly indicate changes in the vertical speed, so that in changes due to elevator, the pointer shows vibrations about a mean position. Furthermore, the pilot would only attain mechanically controlled altitude flying, if he were compelled to keep the pointer of the variometer on that point of a predetermined curve suitable for the airplane and corresponding to the determined altitude. This curve would have to be that of the climbing speed which, for the actual atmospheric conditions could be maintained when the airplane is flown most efficiently, and would, therefore, have to be accurately determined previously and accompany the variometer for the airplane in question. A self-recording variometer would then, within the curve of climbing velocities given by Fig.

19, give a record similar to that shown. In using the variometer,
a further difficulty arises with C and D types* of airplanes,
in consequence of the very great range of their vertical speeds.
For horizontal flight, a variometer, which has high sensitivity in
the neighborhood of the zero position and a large oscillation
range would have to be used and the nozzle adjustment would there-
fore be great. Since the downward speeds possess high values in
C and D types of airplanes, up to 25 m/sec (82 ft/sec) an unad-
justable instrument suitable for horizontal flight fails in gliding
flight. Nozzle adjustments for horizontal, climbing and gliding
flight might eliminate a part of this difficulty, but it is not
suitable for practical use on C and D airplanes, although it can be
used in the present case for scientific experiments. In G and R
types, having a small rate of change in climbing speed, it would be
applicable to a limited extent. Moreover, a variometer is not ab-
solutely essential for horizontal flight, while the large series of
experiments has shown that, with the help of a good altimeter, hori-
zontal flight can be carried out with sufficient accuracy, since
the barographs are so sensitive that, in the barogram (Fig. 20),
even small changes of altitude, in the necessarily short turning
flight (arcs of about 300°), are clearly seen.

Error of the Theodolite Measuring Method.

In a large series of flights with the same airplanes and under
similar conditions, it was found that the base of 1.4 kilometers,
used in the present case, is not reliable for altitudes of over

* Observation and pursuit airplanes.

4000 meters, since the sighting lines intersect at too sharp an angle. Hence the values for 4500 and 5000 meters are omitted. At an altitude of 4000 meters the greatest error was found to be ±3%, from comparisons of a series of measurements. The measurements can also be made for altitudes of 4000 to 7000 meters (13100 to 23000 feet) if a larger base is chosen for the theodolites. The errors are also smaller, if three theodolites are employed, the readings follow more quickly after each other, and the accuracy of the automatic recording theodolites is increased. The above measurements are only the beginning of a larger work on speed measurements, which has been planned for Lake Müritz. A base of 3000 or 5000 meters (9800 or 16400 feet) is there taken and the sequence of readings may be shortened to 1/2 second. It must be left to these detailed experiments to determine the limits of error of the theodolites up to an altitude of 6000 meters (19700 feet). Yet it may be expected that this method can be improved so as to serve for ⸮ calibrating speed indicators for use on airplanes, (Pitot tubes, Venturi tubes, etc.).

The sole aim of the present paper is to remedy the complete lack of data from actual flights and to give the order of magnitude of airplane speeds rather than their accurate values. The investigations described above show, however, that the previously assumed horizontal speeds of airplanes are very far from having been attained and have led to quite erroneous views, not only with us but also in other countries. This astonishing fact is due to not having

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* Bombing airplanes.

carried out reliable speed measurements above 2000 meters (6560 feet). According to English and French reports their customary measuring methods (with camera obscura, etc.) can only be used up to altitudes of 1500 meters (4900 feet).

Translated by
National Advisory Committee
for Aeronautics.
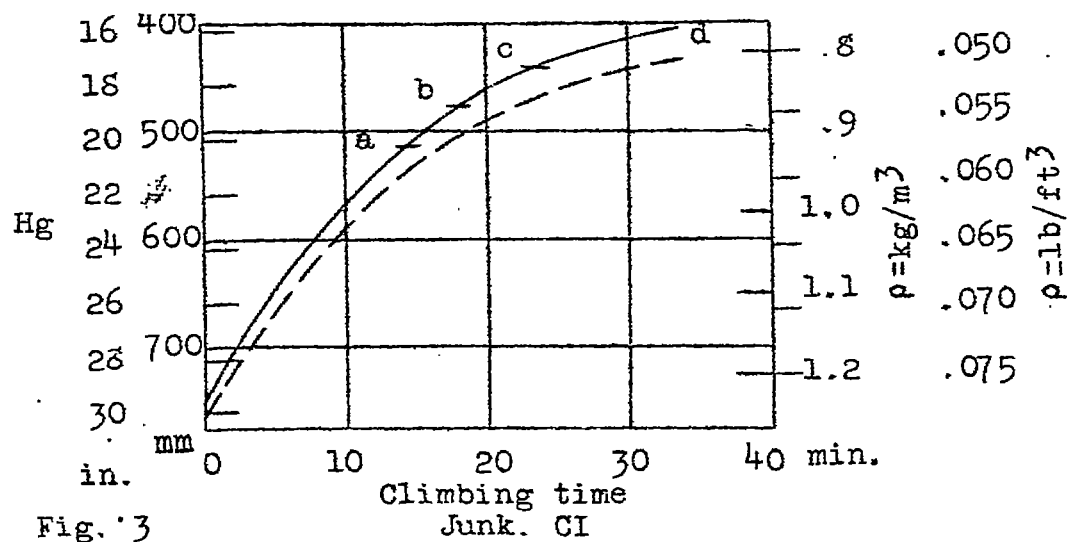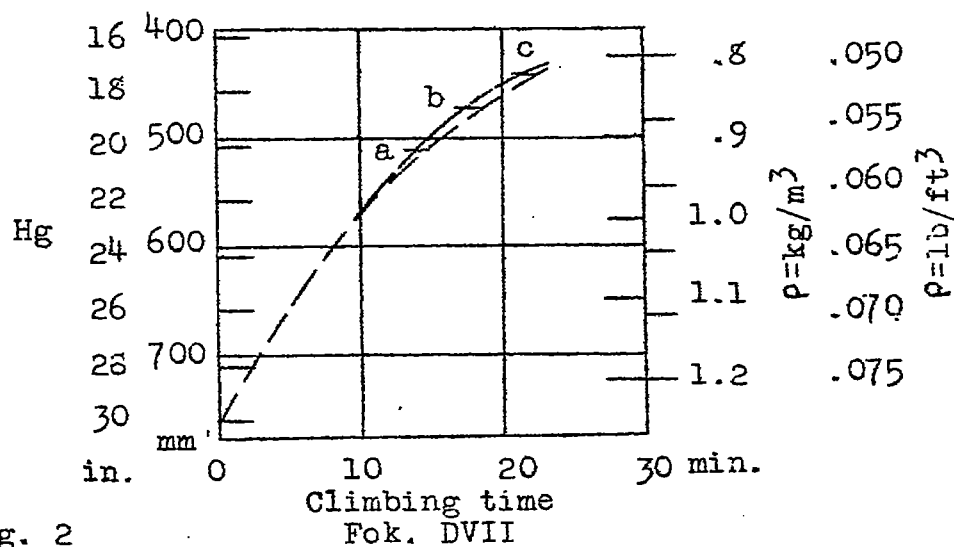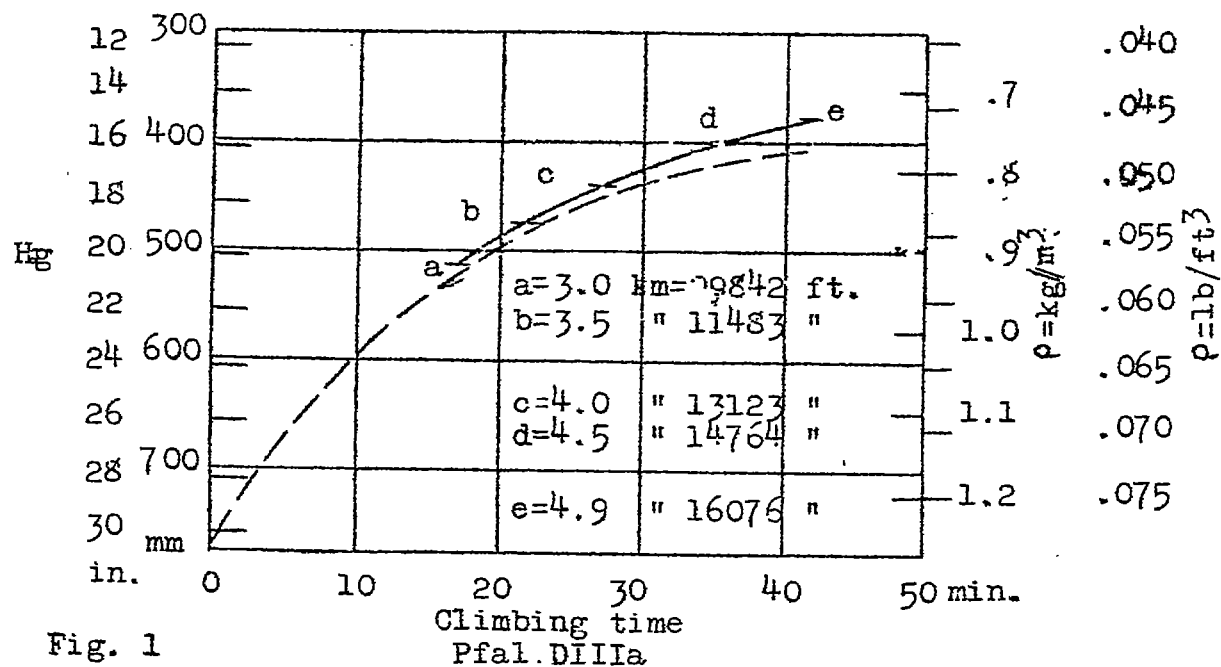
Table 1. Results of recent Speed Measurements.

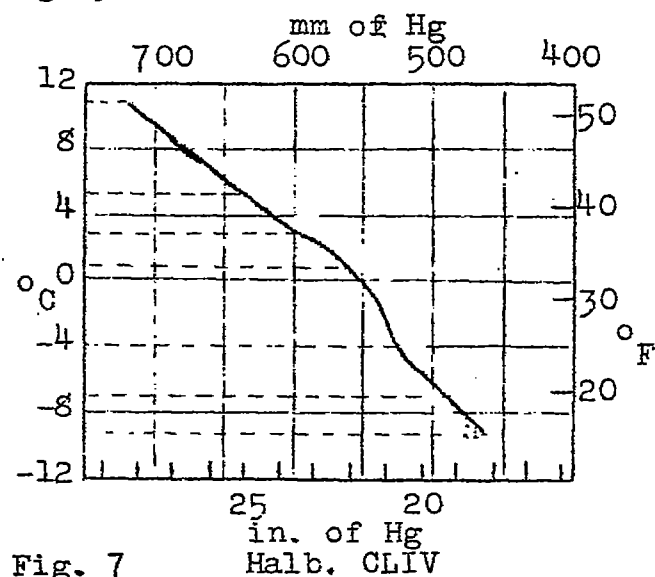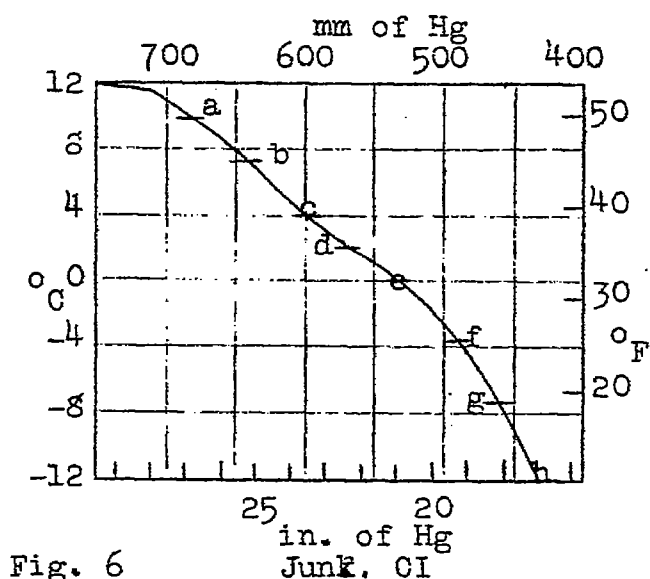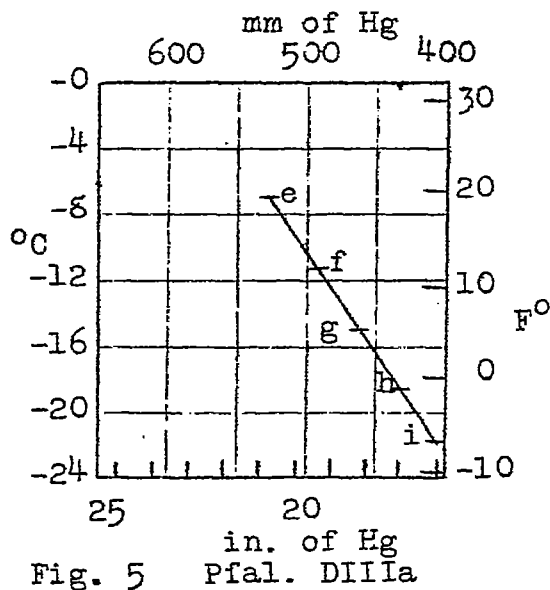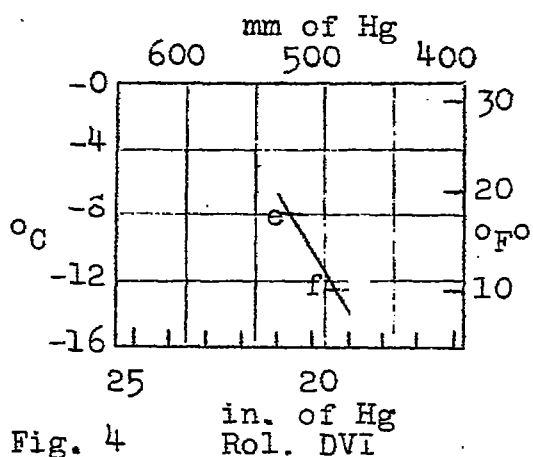| No.	Date of Test	Airplane	Air Pressure		Temperature		Air Density	
			mm. Hg.	in. Hg.	°C	°F	kg/m³ .ρ	lb/ft³ ρ
1	March 5, 1918.	Rol DII a	530 503 480	20.87 19.80 18.90	- 7 -11 -14	19.40 12.20 6.80	0.935 0.890 0.860	.0577 .0556 .0537
2	March 15, 1918.	Pfal D III a	525 488 460 400	20.67 19.21 18.11 15.75	- 7 -12 -15 -22	19.40 10.40 5.00 -4.00	0.920 0.870 0.830 0.740	.0574 .0543 .0518 .0462
3	March 18 1918.	Junk C I	523 485 435	20.59 19.09 17.13	0 -14 -11	32.00 24.80 12.20	0.890 0.840 0.770	.0556 .0524 .0481
4	March 23, 1918.	Halb CI IV	525 492 461	20.67 19.37 18.15	- 4 - 7 - 9	24.80 19.40 15.80 .	0.910 0.860 0.770	.0568 .0537 .0481
5	April 3, 1918.	Fok DVII	535 496 464	21.06 19.53 18.27	- 9 -13 -17	15.80 8.60 1.40	0.940 0.890 0.840	.0587 .0556 .0524
6	April 27 1918	S E	545	21.46	- 8	17.60	0.960	.0599
7	April 9, 1918.	Fok Dr I	538 505 443	21.18 19.88 17.44	- 5 - 7 -12	23.00 19.40 10.40	0.930 0.880 0.790	.0581 .0549 .0493

Table I. Results of recent Speed Measurements (Cont.)

No.	Climbing		Climbing		Barometric height		Height based on yearly mean.	
	Speed m/sec.	Height m.	Speed ft/sec	Height ft.	m.	ft.	m.	ft.
1	--	2842	--	9324	2900	9514	2900	9514
	--	3350	--	10991	3300	10827	3250	10663
	--	3750	--	12303	3700	12139	3550	11647
2	1.95	2955	6.40	9695	3000	9842	2960	9711
	1.85	3450	6.07	11319	3575	11729	3450	11319
	1.65	3980	5.41	13058	4000	13123	3900	12795
	0.70	5000	2.30	16404	5100	16732	4900	16076
3	2.10	2900	6.89	9514	3000	9842	3250	10663
	1.60	3350	5.25	10991	3600	11811	3750	12303
	0.80	4300	2.62	14108	4450	14600	4500	14764
4	--	2950	--	9678	3000	9842	3050	10007
	--	3450	--	11319	3500	11483	3550	11647
	--	3970	--	13025	4000	13123	4070	13353
5	3.00	2775	9.84	9104	2850	9350	2750	9022
	2.55	3250	8.37	10663	3450	11319	3250	10663
	2.20	3780	7.22	12402	3950	12959	3750	12303
6	2.00	2620	6.56	8596	2700	8858	2580	8465
7	4.00	2780	13.12	9121	2800	9186	2800	9186
	3.80	3200	12.47	10499	3300	10827	3300	10827
	2.20	4180	7.22	13714	4300	14108	4300	14108

Table I.   Results of recent Speed Measurements (Cont.)

No.	Horizontal Speed.				Corrected Horizontal Speed.			
	m/sec.	ft/sec.	km/hr.	M.P.H	m/sec.	ft/sec.	km/hr.	M.P.H.
1	41.4	135.83	149.0	92.58	41.4	135.83	149.0	92.58
	39.7	130.25	142.9	88.79	39.7	130.25	142.9	88.79
	37.7	123.69	135.7	84.32	37.7	123.69	135.7	84.32
2	40.5	132.87	145.8	90.60	41.4	135.83	149.0	92.58
	40.6	133.20	146.0	90.72	39.8	130.58	143.2	88.98
	37.7	123.69	135.7	84.32	38.5	126.31	138.5	86.06
	37.0	121.39	133.0	82.64	33.9	111.22	129.2	80.28
3	44.7	146.65	161.0	100.04	44.7	146.65	161.0	100.04
	43.6	143.04	156.0	96.93	44.0	144.36	158.5	98.49
	43.0	141.08	156.0	96.93	43.0	141.08	154.6	96.06
4	41.1	134.84	148.0	91.96	41.1	134.84	148.0	91.96
	37.3	122.37	134.0	83.26	37.3	122.37	134.0	83.26
	34.1	111.88	123.0	76.43	34.1	111.88	123.0	76.43
5	45.0	147.64	162.0	100.66	45.0	147.64	162.0	100.66
	44.5	146.00	160.0	99.42	44.5	146.00	160.0	99.43
	43.2	141.73	156.0	96.93	43.2	141.73	156.0	96.93
6	42.0	137.79	151.2	93.95	42.0	137.79	151.2	93.95
7	43.6	143.04	157.0	97.55	43.3	142.06	155.8	96.81
	40.9	134.19	147.0	91.34	41.3	135.50	148.9	92.52
	38.8	127.30	139.0	86.37	38.4	125.98	138.0	85.75

Fig. 1

Hg

a=3.0 km= 9842 ft.
b=3.5 " 11483 "

c=4.0 " 13123 "
d=4.5 " 14764 "

e=4.9 " 16076 "

$\rho = kg/m^3$ $\rho = lb/ft^3$

Climbing time
Pfal. DIIIa

.040
.045
.050
.055
.060
.065
.070
.075

.7
.8
.9
1.0
1.1
1.2

12 300
14
16 400
18
20 500
22
24 600
26
28 700
30 mm
in. 0   10   20   30   40   50 min.

Fig. 2

Hg

$\rho = kg/m^3$ $\rho = lb/ft^3$

Climbing time
Fok. DVII

16 400
18
20 500
22
24 600
26
28 700
30 mm
in. 0   10   20   30 min.

.8
.9
1.0
1.1
1.2

.050
.055
.060
.065
.070
.075

Fig. 3

Hg

$\rho = kg/m^3$ $\rho = lb/ft^3$

Climbing time
Junk. CI

16 400
18
20 500
22
24 600
26
28 700
30 mm
in. 0   10   20   30   40 min.

.8
.9
1.0
1.1
1.2

.050
.055
.060
.065
.070
.075

Fig. 4   Rol. DVI

Fig. 5   Pfal. DIIIa

Fig. 6   Junk. CI

Fig. 7   Halb. CLIV

Fig. 8   Fok. DVII

a = 1.0 km = 3281 ft.
b = 1.5 km = 4921 ft.
c = 2.0 km = 6562 ft.
d = 2.5 km = 8202 ft.
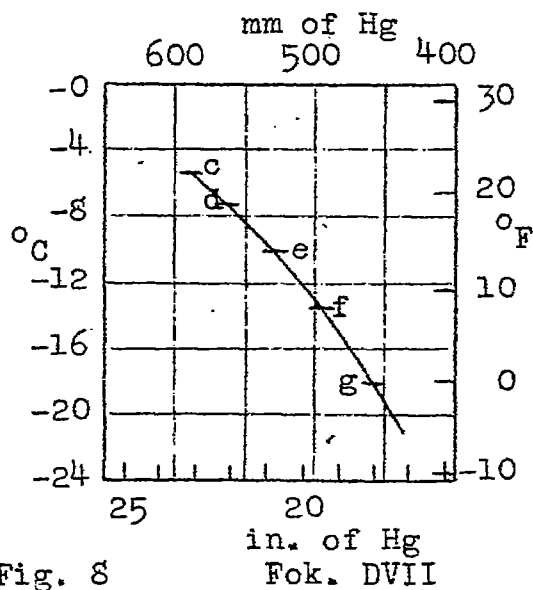
e = 3.0 km = 9842 ft.
f = 3.5 km = 11483 ft.
g = 4.0 km = 13123 ft.
h = 4.5 km = 14764 ft.
i = 5.0 km = 16404 ft.
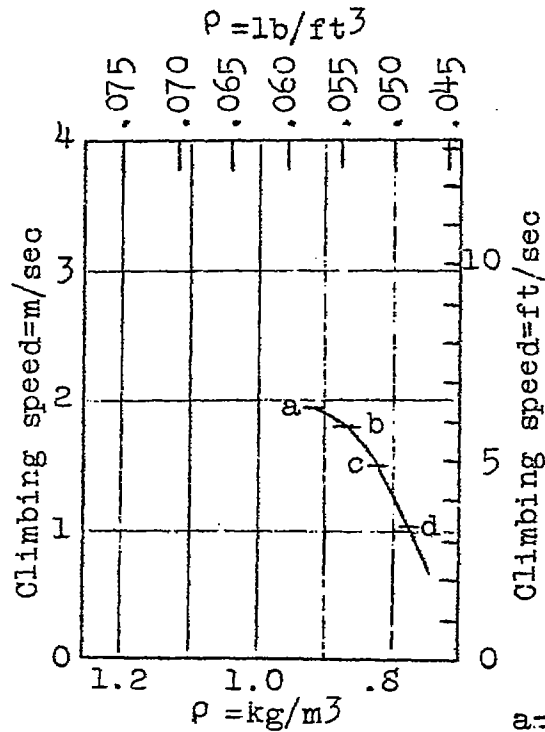
Fig. 9   Pfal.DIIIa

a = 3.0 km = 9842 ft.
b = 3.5 " 11483 "
c = 4.0 " 13123 "
d = 4.5 " 14764 "

Fig. 10   Junk.CI

ρ=lb/ft³

.075 .070 .065 .060 .055 .050

4

Climbing speed=m/sec

3

a

b

c

2

10

Climbing speed=ft/sec

1

5

0

0

1.2 1.0 .8

ρ=kg/m³

a=3.0 km= 9842 ft.
b=3.5 km= 11483 ft.
c=4.0 km= 13123 ft.

Fig. 11 Fok. DVII

Altitude in km

ρ=kg/m³

M.P.H.

75   80   85   90   95   100   105

Altitude in ft.

ρ=lb/ft.³

.7 6.0
     5.0
.8 4.0
.9 3.0
1.0 2.0

.045 16000
.050 12000
.055
.060   8000

IV   I   II   VII   II   VII   III   III   III   V   VI   V   VII

120   130   140   150   160   170

km/hr.
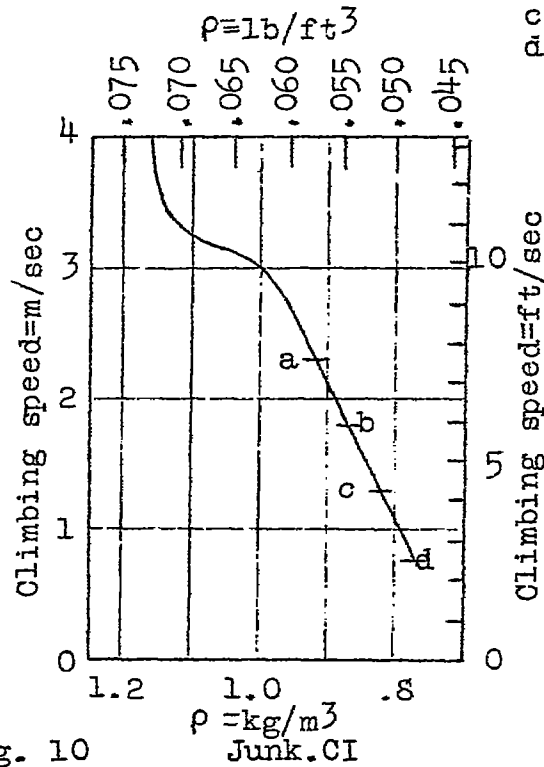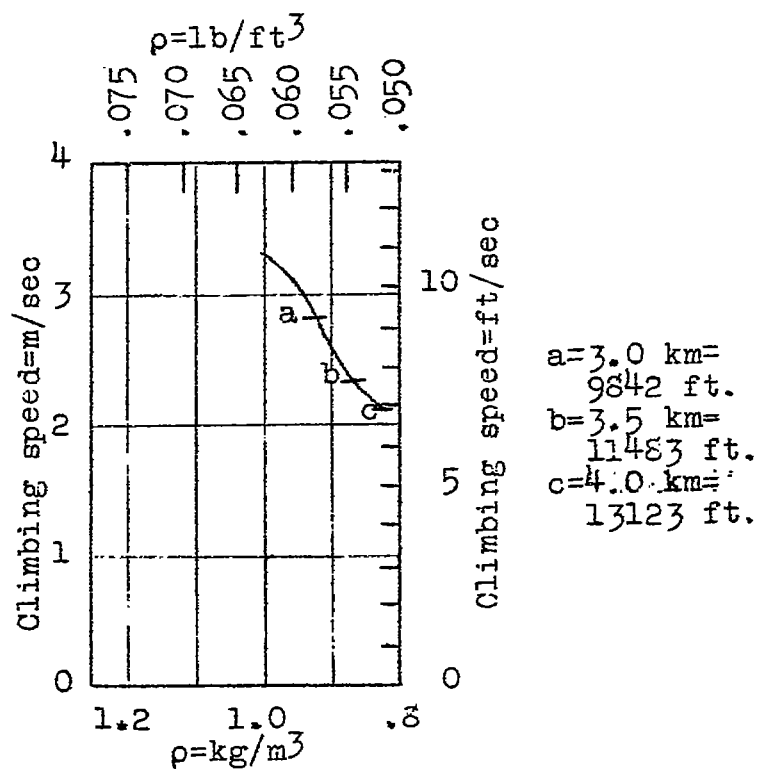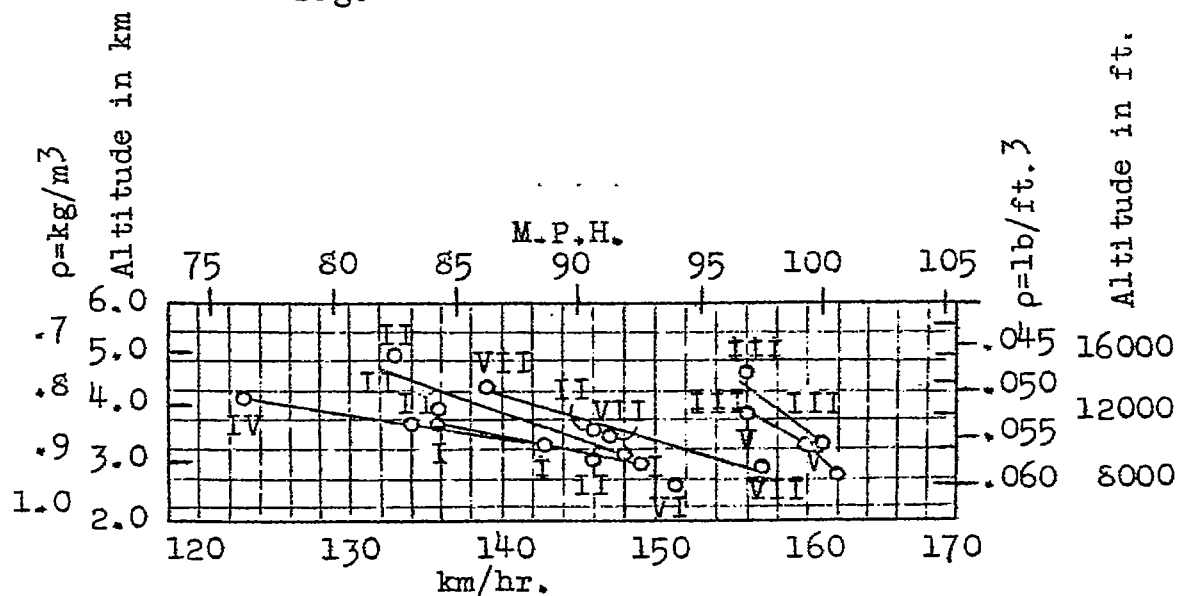
Fig. 12

Horizontal flight
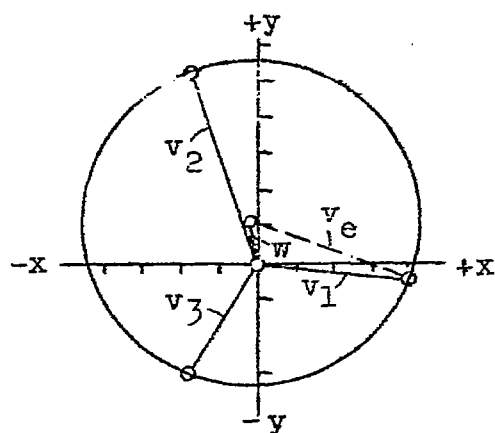
Fig. 13
1st. Triangle
2775 m
9100 ft.
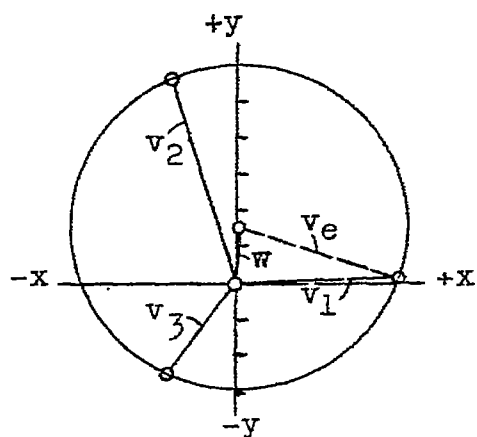
Fig. 14
2nd. Triangle
3250 m
10663 ft.
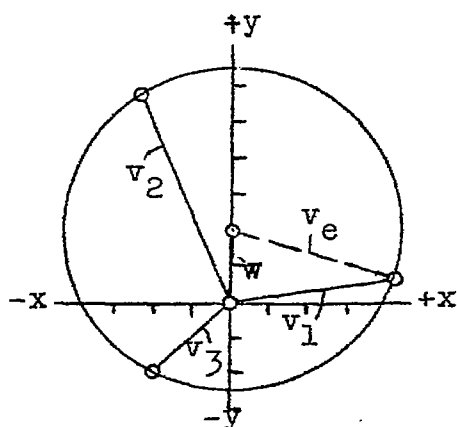
Fig. 15
3rd. Triangle
3780 m
12401 ft.

Fok. DVII

Fig. 13

1st. Triangle, mean altitude 2775 m (9100 ft.)

$v_1 = 40.8$ m/sec (133.86 ft/sec)

$v_2 = 55.3$ " " (181.43 " ")

$v_3 = 35.6$ " " (116.80 " ")

$v_e = 45.0$ " " (100.66 M.P.H.) 162 km/hr.

$w\ \ = 10.7$ " " (35.10 ft/sec)

Fig. 14

2nd. Triangle, mean altitude 3250 m (10663 ft.)

$v_1 = 42.2$ m/sec (138.45 ft/sec)

$v_2 = 60.0$ " " (196.85 " ")

$v_3 = 30.0$ " " (98.42 " ")

$v_e = 44.5$ " " (99.54 M.P.H.) 160 km/hr.

$w\ \ = 16.5$ " " (54.13 ft/sec)

Fig. 15

3rd. Triangle, mean altitude 3780 m (12401 ft.)

$v_1 = 41.9$ m/sec (137.47 ft/sec)

$v_2 = 26.2$ " " (85.96 " ")

$v_3 = 61.3$ " " (201.11 " ")

$v_e = 43.2$ " " (96.64 M.P.H.) 156 km/hr.

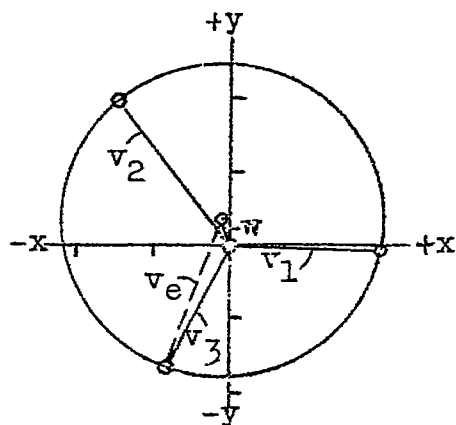$w\ \ = 20.7$ " " (67.91 ft/sec)

Fok.DVII

Fig. 16
1st. Triangle
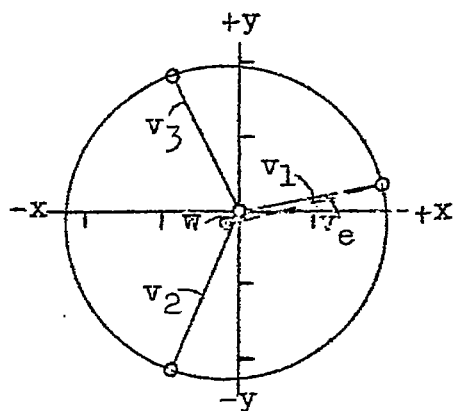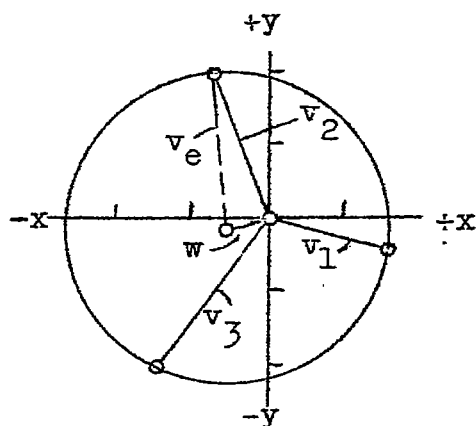2900 m
9514 ft.

Fig. 17
2nd. Triangle
3350 m
10991 ft.

Fig. 18
3rd. Triangle
4300 m
14108 ft.

Junk. CI

Fig. 16

1st. Triangle, mean altitude 2900 m (9514 ft.)

v_1 = 42.1 m/sec (138.12 ft/sec)

v_2 = 51.1 " " (167.65 " ")

v_3 = 39.6 " " (129.92 " ")

v_e = 44.7 " " (96.86 M.P.H.) 161 km/hr.
_____
w = 6.8 " " (22.31 ft/sec)

Fig. 17

2nd. Triangle, mean altitude 3350 m (10991 ft.)

v_1 = 39.5 m/sec (129.59 ft/sec)

v_2 = 47.3 " " (155.18 " ")

v_3 = 41.5 " " (136.15 " ")

v_e = 43.4 " " (97.08 M.P.H.) 156 km/hr.
_____
w = 4.2 " " (13.78 ft/sec)

Fig. 18

3rd. Triangle, mean altitude 4300 m (14108 ft.)

v_1 = 32.8 m/sec (107.61 ft/sec)

v_2 = 43.1 " " (141.40 " ")

v_3 = 50.5 " " (165.68 " ")

v_e = 43.3 " " (96.85 M.P.H.) 156 km/hr.
_____
w = 11.1 " " (36.42 ft/sec)

Junk.CI

Fig. 19

a = .89 kg/m³ = .056 lb/ft³ = ρ
b = .84 "   " = .052 "   " = "
c = .80 "   " = .050 "   " = "
d = .77 "   " = .048 "   " =. "

Fig. 20   Junk. CI